Invisible Clusters and CMB Decrements

Youri Dabrowski

Mullard Radio Astronomy Observatory, Cavendish Laboratory, Madingley Road,
Cambridge, CB3 0HE, UK

Abstract

A decrement in the Cosmic Microwave Background (CMB) has been observed by the Ryle Telescope towards a pair of, possibly lensed, quasars (PC1643+4631 A&B). Assuming that the decrement is due to the Sunyaev-Zel'dovich (S-Z) effect, this is indicative of a very rich intervening cluster, although no X-ray emission has yet been observed in that direction. In order to investigate these problems, we present a new model for the formation of distant spherically symmetric clusters in an expanding Universe. Computation of photon paths allows us to evaluate the gravitational effects on CMB photons passing through the evolving mass (i.e. Rees Sciama effect). The lensing properties of the cluster are also considered so that the model can be applied to the PC1643+4631 case to retrieve both the S-Z flux and the separation of the quasar pair. We find that the Rees Sciama effect might contribute significantly to the overall observed CMB decrement.

1 Introduction

In this paper we model the formation of high redshift galaxy clusters in order to investigate their effect on the CMB. Together with the S-Z effect, we will be concerned with another secondary anisotropy which was first discussed by Rees & Sciama (1968). These authors pointed out that there is a gravitational effect on the CMB photons while they are crossing evolving cosmic structures such as a collapsing cluster of galaxies, since photons climb out of a slightly different potential well than the one into which they entered. In the next section, we present the observations carried out by Jones et al. (1997) which suggest the presence of a rich cluster of galaxies at a redshift $z \geq 1$. Section 3 presents an improved model for the formation of spherical galaxy clusters. This model is applied to the PC1643+4631 observations and the results are summarised in section 4. The work overviewed in this paper is discussed in more details in forthcoming papers (Lasenby et al. 1997 & Dabrowski et al. 1997).

2 Observations

Recent observations carried out with the Ryle Telescope at 15 GHz revealed an intriguing decrement in the CMB towards the pair of quasars PC1643+4631 A & B at red-shift $z \sim 3.8$ and separated by 198 arc-seconds (Jones et al. 1997). Fig.1 shows the CMB decrement together with the quasar positions. If this decrement is due to a S-Z effect, this is indicative of a rich intervening galaxy cluster of total mass
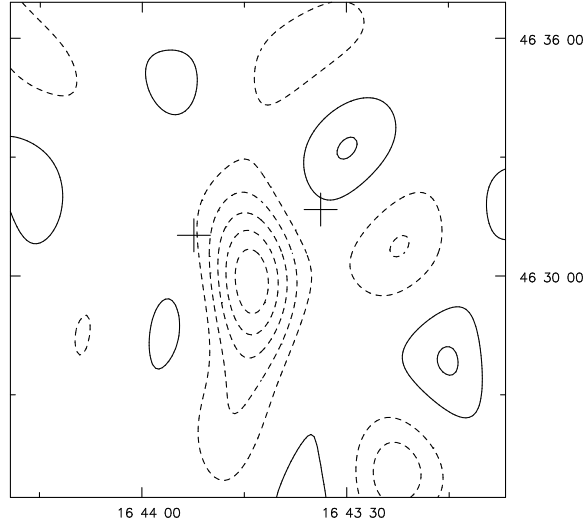
Figure 1: CMB decrement observed by the Ryle Telescope towards PC1643+4631 A & B (Jones et al. 1997). The peak flux density is -380 ± 64 μJy beam^{-1} while the noise level is 38 μJy beam^{-1}. The two crosses indicate the positions of quasars A & B.

$M \sim 10^{15}$ M$_\odot$. Since the quasars' spectra, as observed with the William Herschel Telescope (WHT), are virtually identical, Saunders et al. (1997) suggest that such a massive cluster can account for the spectral similarities if we assume that the quasar pair is lensed. The remarkable aspect of the problem is that no X-ray cluster is visible in this direction. Jones et al. (1997) argue that the absence of a detection with the X-ray Roentgen Satellite (ROSAT) indicates a redshift lower limit of $z \geq 1$ for the expected cluster. Saunders et al. (1997) report colour imaging made with the WHT (R band) and with the UK Infrared Telescope (UKIRT) (J and K bands). The absence of cluster in these observations raises the limit up to $z \geq 1.5$. Recent deep observations (work in progress) have been made with the WHT (U,G,V,R and I bands). Again, no visible clustering is observed, although there exist many objects in the field with expected redshift of $z \sim 1 - 3$. Moreover, the PC1643+4631 case is not isolated. Indeed, a similar situation has also been reported from observations of the CMB with the Very Large Array (VLA) (Richards et al. 1997). The term "dark cluster" seems to have become increasingly popular for such objects (e.g. Hattori 1997 et al., Jimenez et al. 1997, Hawkins et al. 1997).

3   Model

Early attempts to estimate the Rees-Sciama effect induced by a collapsing cluster of galaxies were based on the "Swiss Cheese" (SC) model (e.g. Rees & Sciama 1968, Nottale 1982 & 1984) whereas more recent attempts have used the continuous Tolman-Bondi solution (e.g. Panek 1992). We present here an improved model which, for the first time, treats such a problem exactly. We assume that the cluster
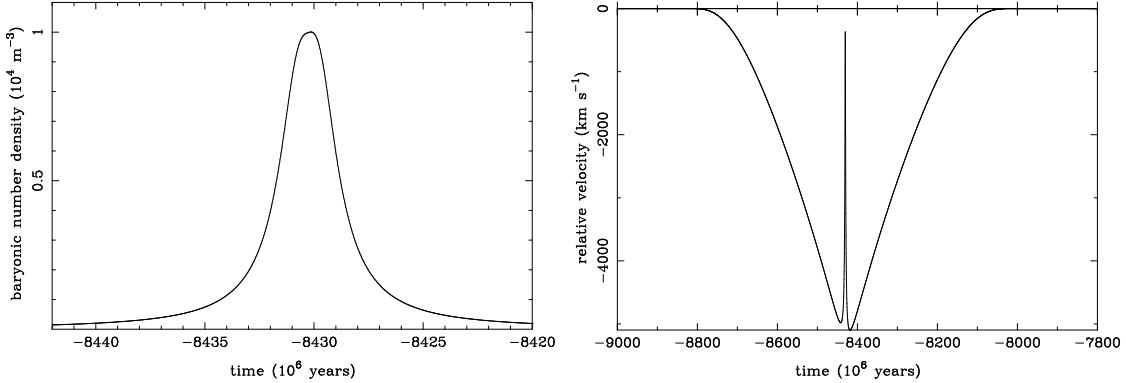
Figure 2: (left) Baryonic number density as a function of proper time t as experienced by a photon traversing the centre of the cluster. A time $t = 0$ would correspond to the present epoch. (right) As for the left case but for the fluid velocity relative to the Hubble flow.

is in a state of pure infall, at the centre of the reference frame. Both the collapsing cluster and the expanding universe are treated as a unique pressure-less fluid, the evolution of which is determined by a set of analytical equations (see Lasenby et al. 1997). The fluid density and velocity field distributions are continuous and realistic (See Dabrowski et al. 1997 and Fig.2) which is a major improvement over the SC models. Indeed for the SC case, an artificial vacuum region is needed to isolate the cluster from the universe which implies an unrealistic cluster density profile as well as discontinuities in the density and velocity field distributions. Another advantage with regard to the SC models is that our perturbation is initially defined by only two free parameters rather than three in the SC case. Initially, the density of our fluid is uniform and only the velocity field is perturbed in order to form a realistic cluster. In a given cosmology this perturbation is controlled by a size parameter and a rate of growth parameter. In addition to the evolution of the fluid we perform the exact calculation of photon trajectories and redshifts (Dabrowski et al. 1997) so that effects such as Rees-Sciama or gravitational lensing can be fully appreciated.

4   Results

We now apply our model to the PC1643+4631 case in order to estimate the typical properties of clusters which may explain the observations of Jones et al. (1997). Our aim is to account for both the CMB decrement and the lensing of the quasar pair. We assume that the lensing effect will be correctly taken into account if the Einstein ring radius is 100 arc-seconds. Throughout this paper, we assume the following cosmology: $\Omega(t) = 1$, $H_0 = 50$ km s^{-1} Mpc^{-1}. In order to obtain quantitative results we need to constrain our model parameters. We assume that the cluster lies at a redshift $z = 1$ and that $z = 3.8$ for both quasars A & B. We also consider a very rich cluster and fix the maximum baryonic number density experienced by an observed photon to 10^4 m^{-3} and the total gravitational mass over baryonic mass

ratio is taken to be 10. In order to obtain an Einstein ring radius of 100 arc-seconds we find that the core radius R_c has to be 0.45 Mpc. R_c is defined as the radius at which the cluster energy falls to one-half its maximum value. We find that the total mass contained within a sphere of 2 Mpc is 7.8×10^{15} M$_\odot$ and 1.9×10^{16} M$_\odot$ within a sphere of 4 Mpc. The density and fluid velocity experienced by a photon passing through the centre of the cluster are shown in Fig.2. We find that the density profile can be fitted accurately (Dabrowski et al. 1997) by a standard King profile model known to represent realistically observed clusters (Rood et al. 1972 & Sarazin 1988).

We now investigate the effect of such a cluster on the CMB. Firstly we compute the temperature T_e required to produce a total S-Z flux of -380 μJy on the Ryle Telescope. We find $T_e = 1.78 \times 10^7$ K and that the corresponding S-Z temperature decrement is $\Delta T_{\mathrm{SZ}} = 458$ μK. Since our model allows photon path and redshift calculation we are able to estimate the Rees-Sciama effect and we find $\Delta T_{\mathrm{RS}} = 178$ μK. We then conclude that the Rees Sciama effect is not negligible and might contribute significantly to the total observed CMB decrement.

References

[1] Dabrowski, Y., Hobson, M.P., Lasenby, A.N. et al., 1997. *MNRAS*, submitted.

[2] Hattori, M., Ikebe, Y., Asaoka, I. et al., 1997. *Nature*, 388, 146.

[3] Hawkins, M.R.S., Clements, D., Fried, J.W. et al., 1997. *MNRAS*, in press.

[4] Jimenez, R., Heavens, A.F., Hawkins, M.R.S. et al., 1997. *MNRAS*, in press.

[5] Jones, M.E., Saunders, R., Baker, J.C. et al., 1997. *ApJ*, 479, L1.

[6] Lasenby, A.N., Doran, C., Hobson, M.P. et al., 1997. *MNRAS*, submitted.

[7] Nottale, L., 1982. *A & A*, 110, 9.

[8] Nottale, L., 1984. *MNRAS*, 206, 713.

[9] Panek, M., 1992. *ApJ*, 388, 225.

[10] Rees, M.J., Sciama, D.W., 1968. *Nature*, 217, 511.

[11] Richards, E.A., Fomalont, E.B., Kellermann, K.I. et al., 1997. *AJ*, submitted.

[12] Rood, H.J, Page, T.L., Kintner, E.C. et al., 1972. *ApJ*, 175, 627.

[13] Sarazin, G.L., in *X-ray emissions from clusters of galaxies*, 1988. Cambridge University Press, p 168.

[14] Saunders, R., Baker, J.C., Bremer, M.N. et al., 1997. *ApJ*, 479, L5.